Topology Realization using Gain Control for Wireless Testbeds

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ABSTRACT

Wireless testbeds present a convenient and cost effective option for researchers in communications to validate their work. The main drawback of these testbeds is their reliance on nodes with fixed placement; this limits experimenters ability to test protocols that depend on a complex connectivity between the nodes such as relaying. In this work, we present a way to overcome this limitation; this method attempts to realize a given topology between a set of nodes by adjusting each node's transmit power and receive gain in a manner to connect and disconnect the links between the nodes as desired. We start by expressing the topology realization as an optimization problem using two different forms. The topology realized is dependent on some characteristics of radio-frequency (RF) hardware. Hence, we evaluate theses parameters for a specific platform. A computer evaluation for the two formulations is carried out, followed by a real world experiment to validate the proposed method. During this experiment, the values of gains required to realize a given topology are calculated, then tested using hardware.

CCS Concepts

•**Networks** → **Physical topologies;** *Physical links;*
•**Hardware** → Wireless devices;

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Keywords

Wireless Topology; Software Defined Radios; Wireless Testbed

1. INTRODUCTION

Wireless researchers trying to validate their work have several options. The first and most popular option is simulations. The problem with using simulators is in the abstractions they use, which might hide some aspects of hardware and wireless environment. The second option is purchasing and deploying hardware. This choice is not accessible to all researchers due to the cost associated with high-end RF devices like SDRs (Software Defined Radios). Besides, the low utilization of hardware, if acquired, makes this option uneconomical. This makes using remotely accessible testbeds the most suitable method, as it enables researchers to work using real hardware without the trouble and cost of purchasing and setting up equipment.

Testbeds, despite being more realistic, impose restrictions on experimenters. As most wireless testbeds that are accessible remotely use fixed installations for their nodes, testbed users do not have the capability to change the placement of the nodes the way they desire. They are also bound to the capabilities of the available hardware. These factors (placement and hardware) limit the topologies achievable by an experimenter. In order for a wireless testbed to be able to accommodate various experiments with their topology requirements, despite having a fixed node placement, a method to modify connectivity to realize different topologies is needed.

Transmit power has been used to control the topology in ad-hoc networks. In [7], a distributed algorithm where each node makes a local decision on its transmission power to guarantee global connectivity was suggested. In [5], to create a desired topology an optimization problem is proposed with the purpose of reducing the maximum power used in an ad-hoc network; greedy algorithms were developed to calculate the values of the transmitted power. Both these methods, although they use transmit power to control topologies as our work, make assumptions that are not valid for testbeds. ORBIT testbed [6] enables its users to realize topologies. ORBIT consists of a 20×20 nodes grid, each node having a WiFi interface. All these nodes get allocated to a single user. To realize a topology, ORBIT's method [3] uses organized trial and error to map the topology to nodes in the grid. The problem with ORBIT's topology realization is its reliance on the availability of excess nodes. To realize a 5 node topology, a user must have exclusive access over all 400 nodes.

Given a set of wireless nodes and a desired topology between them, our proposed method adjusts their transmit powers and receive gains to realize the topology. This method gives users the flexibility of setting the connectivity between the nodes the way they desire, thus, overcoming the limitation imposed by fixed node placements. The suggested method relies on knowing, for each type of modulation, the minimum power at receiver for a wireless link to be considered connected and the maximum power for a link to be disconnected. These powers are constant for a given hardware platform. After measuring the channel coefficients between the nodes and knowing these constants, we formulate the topology realization as an optimization problem, which is solved to obtain the gains. Compared to the method proposed by ORBIT, our solution has the advantage of not needing more nodes than the number required by the experiment.

The rest of the paper is organized as follows; a motivating scenario highlighting the need for a topology realization method is presented in Section 2. In Section 3 the needed background information is presented. Section 4 discusses two formulations of the problem. The hardware dependent factors are calculated for the SDR platform of choice in Section 5. While in Section 6, the two suggested methods are compared and a real world experiment is performed to validate this work. Section 7 discusses the limitations of this method.

2. MOTIVATING SCENARIO

To motivate our work, we consider the following scenario. A user wants to experiment with different relaying schemes to extend the possible range of communication. To test such a scenario the user wants a specific topology to be realized; he wants the transmitter and the receiver nodes to be out of range of each other and the relay node should be capable of communicating with both nodes.

Let us discuss how this topology can be realized. If the user physically possesses three nodes, placed in an arbitrary placement as shown in Figure 1 in black. Each node has a transmission range r_t shown as dashed circles. The user will move them to positions similar to the ones drawn in blue in Figure 1.

A remotely accessible testbed user will not be able to move the nodes. Assuming he has access to a big number of nodes. Instead of physically moving the nodes, he will use trial and error until he finds nodes that realize his topology. The method used in ORBIT testbed performs this mapping for the user.

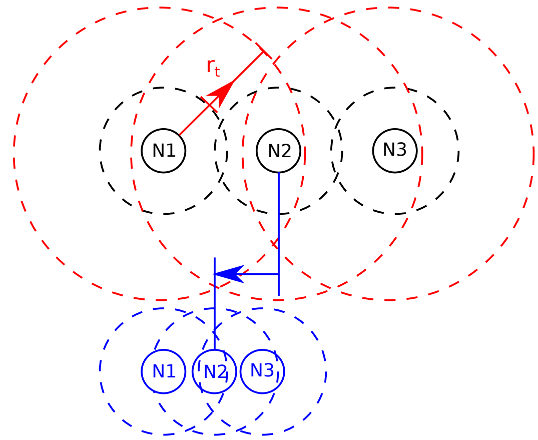


Figure 1: To test a relay scenario, starting from nodes displayed with black, the user can change gains as shown in red, or change the placement of nodes shown in blue. Dashed circles present the transmission range.

Assuming the user only has only three nodes, he will change the gains to realize the topology. For example, he will attempt to tune the transmit power of node 1 until node 2 can receive but 3 will not be able to receive. This can be visualized as the user changing the radius of transmission r_t. This scenario is highlighted in red in Figure 1. Our proposed method determines these gains for the user.

3. BACKGROUND

3.1 Wireless Channel

The connectivity of nodes in a testbed does not only depend on the distance between the nodes, it also depends on the environment surrounding them. Some of these factors include whether the nodes are placed in line of sight (LOS) of each other or not, the material and thickness of the walls, etc. These are just the static factors; other factors of random nature are also present. If the testbed is placed in a non dedicated room (for example in hallways), the movement of the people in the building, the location of the furniture, etc, will result in non deterministic changes in the channel coefficients between the testbed nodes. Any system that attempts to realize a topology must try to keep it stable despite these channel variations.

3.2 Quality Metric

In communications, several metrics can be used to assess the quality of the received signal, such as Bit Error Rate (BER) or Packet Error Rate (PER). Based on the value of the quality metric, we will consider two nodes to be connected or disconnected. In this work, we selected the packet error rate as the performance metric. The reason for selecting PER over BER is its ease of calculation. To calculate BER the receiver needs to be aware of the transmitted data and has to be synchronized with the transmitter. This is will add unjustified complexity to the implementation. PER on the other hand can be calculated by checking the cyclic redundancy check (CRC) of the received packet. We will consider a link between two nodes connected if the PER of this link is below 10% and a link disconnected if the PER is of this link is above 90%. In between, the link state will be assumed undecided and we will try to keep links away from this state.

3.3 SDR characteristics

Several characteristics of an SDR platform contribute to the realization of a topology. Some of them are relevant to the transmit chain and others to the receive chain.

3.3.1 *Transmit chain*

The power levels that the transmit chain can provide help in determining the connectivity it can achieve. The higher the maximum power level is, the bigger the distance that it can cover. Assuming the transmitted power is digitally controlled (can only take a discrete set values) by setting the transmit gain (tx-gain), the difference between two possible values in the variable power levels determines to which extent the user has control on the transmitted power. The purpose of this work is to have control over the topology, allowing some nodes to communicate with each other while other nodes cannot. This is the reason why having fine grained control over the power level is desirable.

3.3.2 *Receive chain*

As discussed in [4], the receiver sensitivity is defined as the signal level required for a particular quality of received information. Receiver sensitivity plays an important role in determining whether two nodes are connected or not. It depends on how the receiver circuit is implemented and the noise figure of each of its components; this makes it depend on the SDR kit used. Receiver sensitivity value depends on the type of modulation used. Also, the receive chain could contain a receive gain (rx-gain) which can be used to properly condition the received signal.

Note that both chains suffer from nonlinearities, so increasing tx-gain above a certain level could lead to distortion. Also, SDRs are built to operate over a wide range of frequencies and their RF characteristics vary with frequency.

4. PROBLEM FORMULATION

Let us suppose that a testbed user has reserved N nodes. Node i has two variables: transmitted power p_i^T in dBm and amplification at receiver a_i^R in dB. The user wants to realize a topology on his N nodes defined by an $N \times N$ connectivity matrix C; each element c_{ij} where $i \neq j$ takes a value of 1 if the user wants the directional link between nodes i and j, L_{ij}, connected and zero otherwise (the diagonal elements are meaningless). Then let us define the set of connected directional links CL which corresponds to all L_{ij} where c_{ij} equals one, and the set of disconnected links DL which corresponds to all L_{ij} where c_{ij} equals zero.

h_{ij} is the channel coefficient between nodes i and j in dB. We assume that the channel coefficients between the testbed nodes are already known (they can be measured either periodically or before attempting to realize the topology). Channel coefficients depend on multiple factors like the distance between the nodes, the obstacles between them, etc. They are subject to random variations due to changes in the environment.

P_C^{mod} is the minimum received power in dBm from one node to the other for the link between them to be connected according the definition made in Section 3.2 when using a modulation of type mod. P_D^{mod} is the maximum power received to consider the link to be disconnected when using mod. Both P_C^{mod} and P_D^{mod} are dependent on the characteristics of hardware used and can be evaluated as will be explained later.

For the user desired topology defined by the matrix C to be realized on the N nodes using modulation of type mod the following conditions must be satisfied

$$p_i^T + h_{ij} + a_j^R \geq P_C^{mod}, \{i, j \mid L_{ij} \in CL\} \qquad (1)$$

$$p_i^T + h_{ij} + a_j^R \leq P_D^{mod}, \{i, j \mid L_{ij} \in DL\} \qquad (2)$$

The LHS of equations (1) and (2) presents the power received by node j from node i in dBm. Equation (1) is for connected links and Equation (2) is for disconnected links. Additionally, there are hardware constraints like the minimal and maximal possible values of gains, which will be mentioned later.

There are several ways to define an optimal solution among all feasible points. One of these could be minimizing the transmitted power ($\min \sum p_i^T \ \forall \ i$). Considering that the testbed uses fixed nodes which draw their electricity from the power grid and are not battery powered, power is not a crucial factor. What is more important than power is the robustness of a solution. As mentioned earlier, channel coefficients are subject to random variation. If the selected solution is on the boundary of the feasible region formed by the constraints, any variation in channel coefficients could move the solution outside of the feasible region. A better solution would be more robust against the expected variation in channel coefficients.

4.1 Maximizing Minimum Slack Formulation

In a testbed with N nodes, we have $N \times (N-1)$ channel coefficients, each of them is subject to random variation. Each link L_{ij} has a slack s_{ij}. If the channel coefficient of this link, h_{ij}, changes within the slack in the direction opposite to what we desire (increased for links we want disconnected or decreased for links we want connected), the solution obtained will remain feasible. The objective of this formulation is to maximize the minimum of all slacks, as follows

$$\max s \ , \tag{3}$$

where $s = \min s_{ij} \ \forall \ i \neq j$. The problem constraints are

$$p_i^T + h_{ij} - s + a_j^R \geq P_C^{mod}, \{i, j \mid L_{ij} \in CL\}, \tag{4}$$

$$p_i^T + h_{ij} + s + a_j^R \leq P_D^{mod}, \{i, j \mid L_{ij} \in DL\}. \tag{5}$$

This problem can be solved using a Linear Programming solver.

4.2 Transmitter Biased Formulation

The problem with the previous formulation is the symmetry between p^T and a^R. As we will discuss later, the increase of receiver amplification a^R is not always guaranteed to improve the signal quality. Realizing the solution using values of p^T bigger than a^R, if possible, is preferred. This can be done by giving a higher priority to p^T using the objective function. Such objective is hard to describe using a linear formulation. Hence, we modify the formulation as follows. We start by transforming all variables in dBm to mW and dB to ratio using

$$p_i^{r.T} = 10^{\frac{p_i^T}{10}}, \ \ a_i^{r.R} = 10^{\frac{a_i^R}{10}}, \text{ and } \ h_{ij}^r = 10^{\frac{h_{ij}}{10}}. \tag{6}$$

The r in superscript denotes the variable transformed to ratio. The same transform is applied to the constants $P_D^{r.mod}$ and $P_C^{r.mod}$. The objective we chose is

$$\min \sum_{i,j|L_{ij}\in DL} (p_i^{r.T})^2 \times h_{ij}^r \times a_j^{r.R} + 10^{\alpha} \times \sum_{i,j|L_{ij}\in CL} \frac{1}{(p_i^{r.T})^2 \times h_{ij}^r \times a_j^{r.R}}. \tag{7}$$

The first term represents the received power from the undesired links which we are trying to minimize, while the second is the inverse of the received power from the desired links which we are trying to maximize. The parameter α controls whether disconnecting the unwanted links or connecting the wanted ones has a higher priority. The squaring of $p_i^{r.T}$ forces the solver to be biased towards the transmitted power, $p_i^{r.T}$, and gives it a higher priority. This formulation can be solved using a geometric programming solver. The problem constraints after applying the transformations become

$$p_i^{r.T} \times h_{ij}^r \times a_j^{r.R} \geq P_C^{r.mod}, \{i, j \mid L_{ij} \in CL\}, \tag{8}$$

$$p_i^{r.T} \times h_{ij}^r \times a_j^{r.R} \leq P_D^{r.mod}, \{i, j \mid L_{ij} \in DL\}. \tag{9}$$

5. PARTICULARIZATION TO A HARDWARE PLATFORM

In order to use this method, first, the characteristics of the used hardware platform need to be evaluated. The constants P_C^{mod} (minimum power for a link to be connected when using modulation type *mod*) and P_D^{mod} (maximum power below which a link is considered to be disconnected when using modulation type *mod*) are hardware-dependent. For instance, receiver with a lower noise figure will have a lower value of P_C^{mod}, and hence, will be capable to decode signals with lower power. Other than the values of the constants, the previously mentioned constraints are not sufficient to describe actual RF hardware. As, there are constraints dictated by the hardware, for example, the minimal and maximal powers that can be transmitted.

We will illustrate how the problem can be adapted using a USRP N210 [1] using WBX daughterboard. A USRP i has two variables tx-gain g_i^T and rx-gain g_i^R. g_i^T and g_i^R are related to the power transmitted in dBm (p_T^i) and the amplification at the receiver (a_R^i) using the following relations

$$p_T^i = g_i^T + P_{\min}^T \text{ and } \ a_R^i = g_i^R + A_{\min}^R, \tag{10}$$

where $P_{\min}^T$ is the minimal power in dBm which the USRP transmits and $A_{\min}^R$ is the minimal amplification, in dB, which the USRP receive chain provides. Power measurements reported by the USRP are not calibrated; the values reported by a USRP should be adjusted to the true power by a factor as follows

$$p_i^{rep} = p_i^R + C^R, \tag{11}$$

where p_i^R is the true power received by the USRP in dBm, C^R is the calibration factor in dB and p_i^{rep} is the reported power which is referenced to an unknown power level and we will refer to its unit as dBx. When one USRP is transmitting to another the received power can be expressed as

$$p_i^R = p_i^T + h_{ij} + a_j^R, \tag{12}$$

which can be rewritten in terms of the known values as

$$p_i^{rep} = g_i^T + h_{ij} + g_j^R + X, \tag{13}$$

where X is a constant which equals $P_{\min}^T + A_{\min}^R - C^R$.

As long as all the nodes are USRPs of the same type and do not exhibit large variability, the value of X will be constant for all calculations. We will carry on with all power measurement measured in dBx and the value of X will be part of the RHS constants in all inequalities.

In this section, we first start by describing the hardware constraints concerning the possible set of gains. Then, we study the relation between tx-gain and the packet delivery ratio[1]. Afterwards, we study the effect of changing the rx-gain on delivery ratio. From these

[1]Packet Delivery Ratio = 1 - Packet Error Rate

relations, we will determine the thresholds[2] P_C^{mod} and P_D^{mod}. Unless otherwise stated, measurements in this section were obtained by taking the average of multiple readings.

5.1 USRP constraints

The USRP hardware has a discrete set of values for the gains. Besides the minimal and maximal values for gains ($G^T_{\min}$ and $G^T_{\max}$), the gains can only take values that are multiples of half. Hence, the following constraints are added,

$$G^T_{\min} \le g_i^T \le G^T_{\max}, \quad g_i^T = k/2, \ k \in \mathbb{Z} \ , \tag{14}$$

$$G^R_{\min} \le g_i^R \le G^R_{\max}, \quad \text{and} \quad g_i^R = k/2, \ k \in \mathbb{Z} \ . \tag{15}$$

5.2 Relation between received power and packet delivery ratio

To quantify the relation between the received power and the packet delivery ratio, a transmitter and receiver were configured to operate for a period of 10 seconds; after that period the receiver reports the average power received and the packets' delivery ratio. As the packet delivery ratio depends on the packet size, we have to mention that for all experiments performed in this work packets with a payload of 1500 bytes were used. To ensure the validity of the results, multiple runs were conducted in a random order covering different modulation types and different values of tx-gain and Values obtained were averaged. Results are shown in Figure 2. From this figure, the received power needed to obtain the threshold for a link to be connected or disconnected (more than 90% and less than 10% delivery ratios, respectively) for a given modulation type could be obtained. While making the measurements for this figure only tx-gain was changed; the effect of rx-gain will be discussed in the next section.

As the power received increases the delivery ratio would remain near 100% until the USRP's amplifiers start to saturate. If the power received by a USRP exceeded a threshold, the amplifiers in the RF front-ends will start saturating. This will cause a distortion in the signal and worsen the delivery ratio. To measure this level, two USRPs were placed in proximity of each other. Gains were varied and power and delivery ratio at receiver were measured. The results are shown in Figure 3. The following constraint will be added to account for saturation

$$g_i^T + h_{ij} + g_j^R \le P_{SAT}^{X.BPSK}, \{i, j \mid L_{ij} \in CL\}, \tag{16}$$

where $P_{SAT}^{X.BPSK}$ is the maximal power received in dBx to avoid saturation. X in the superscript denotes a value in dBx.

[2]The results obtained are not guaranteed to be valid for all similar hardware because electronic components are subject to batch variability, though for the USRPs used no major variability was found.

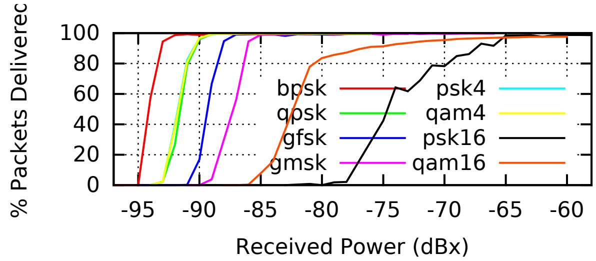


Figure 2: Relation between the received power and the packet delivery ratio for different types of modulation.

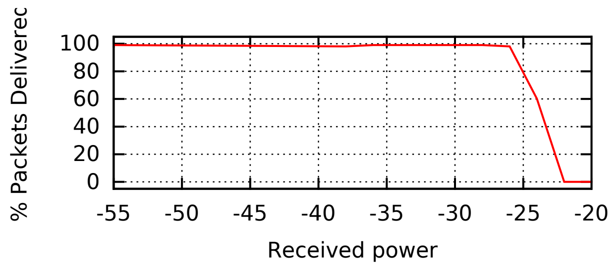


Figure 3: Saturation occurs when the power received is too high. BPSK modulation was used.

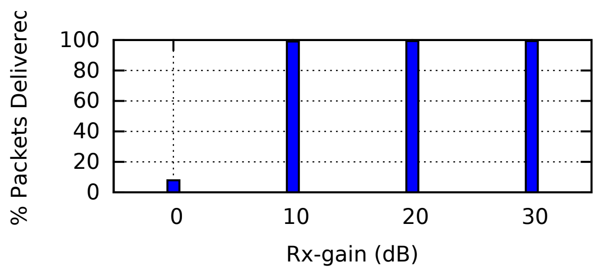


Figure 4: The effect of changing the rx-gain on packet delivery when tx-gain is constant.

5.3 Effect of changing rx-gain on packet delivery ratio

Theoretically, increasing the rx-gain at the receiver should have no effect on the throughput, as the rx-gain increases both the signal and noise powers. Nevertheless, when taking into consideration the complexity of the receiving circuit, the rx-gain helps condition the received signal to meet the dynamic range of the Analog to Digital Converter (ADC). It can either amplify it to exceed the noise floor of a component or attenuate it to avoid saturation. This argument is supported by observing the delivery ratio while only the rx-gain is changing as shown in Figure 4.

Although the rx-gain has caused an improvement in delivery ratio as shown in Figure 4, increasing the rx-gain does not always improve reception. If the power arriving at the receiver of the antenna is too low (either due to weak transmission power or any other reason), increasing the rx-gain would increase the received power level (probably due to the amplification of noise), but it would have no effect over packet delivery. To investigate this, measurements were made where the sum of both tx-gain and rx-gain was held constant at 30 dB; the contribution of tx-gain to this sum of gains of 30 dB was varied, while observing the received power and the packet delivery ratio. In Figure 5a, increasing the tx-gain and reducing the rx-gain keeps the received power almost constant while the packet delivery ratio changes as shown in Figure 5b. To account for this phenomenon, a new variable is introduced *Power at Receiver Antenna*; this value is not measured directly, and is obtained by subtracting the value of rx-gain from the power received. Its value for the same measurements is shown in Figure 5c. From this Figure, and other conducted measurements, the power at the receiver antenna for correct reception should be bigger than $P_{AC}^{X.BPSK}$ which is the minimum power at the antenna for a link to be connected.

This will be incorporated into the problem by adding the following constraint

$$g_i^T + h_{ij} \leq P_{AC}^{X.BPSK}, \{i, j \mid L_{ij} \in CL\}. \quad (17)$$

6. CASE STUDY

6.1 Problem Formulation

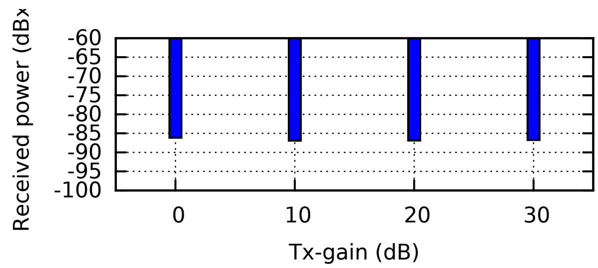
In this section, we will discuss an implementation of the proposed problem for a specified connectivity. The topology we are trying to realize is shown in Figure 6. In this topology, links on the sides of the rectangle formed by the nodes should be connected (belong to CL) while the ones on the diagonals are supposed to be disconnected (belong to DL). We will confine ourselves here to BPSK modulation, although our method should be valid for any other type of modulation.

This topology can be used, for example, to test cognitive radio networks routing protocols, where node 1 is sending and receiving data from node 4. Due to the activity by a primary user the direct link from node 1 to node 4 can no longer be used. The cognitive routing protocol will reroute packets to node 4 through nodes 2 and 3.

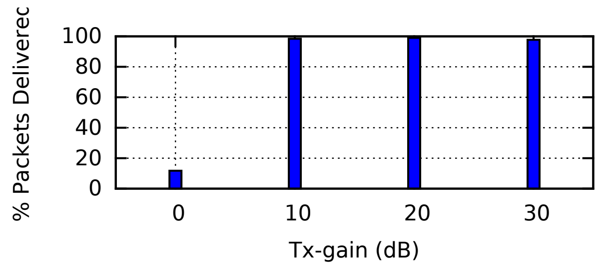
6.2 Evaluation

Both the *Maximizing the Minimum Slack Formulation (MMSF)* and the *Transmitter Biased Formulation (TBF)* were evaluated using channel coefficients values that were measured using real hardware, though values in this section were only evaluated mathematically. The MMSF was solved using a Mixed Integer Linear Programming (MILP) solver; GLPK (GNU Linear Programming Kit) was used. The TBF was solved using a geometric programming solver; CVX [2] was used and the gain values obtained in ratios from CVX were transformed to dB and then rounded to the nearest half.

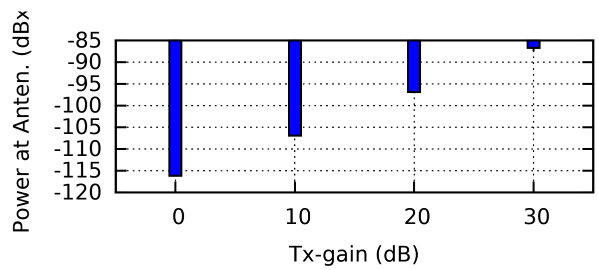
We now compare the two formulations, by solving them for the same channel coefficients; the values of slack variables, s_{ij}, calculated from both solutions are shown in Figure (7). From this Figure, we can see that the slack of the link L_{21}, L_{23}, L_{24} , and L_{42} using MMSF is 0.5 dB while it is zero for the TBF. This is one of the advantages of the MMSF as it guarantees a minimal slack for all links. The TBF, on the other hand, gives a solution with higher values for transmit gains on the average. Other than that, the MMSF uses an MILP solver which is orders of magnitude faster than the GP



(a) Power Received



(b) Packets Delivery Ratio



(c) Power at the antenna

Figure 5: From top to bottom power received, packet delivery ratio and estimated power at the antenna when the sum of tx-gain and rx-gain is held constant at 30 dB.

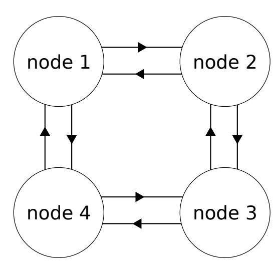


Figure 6: The topology of the case study, side links are connected, diagonal links are disconnected.

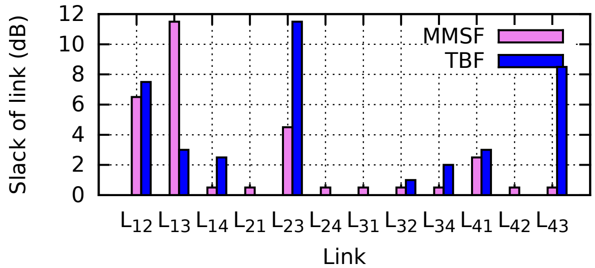


Figure 7: Comparison of the slack obtained the GP and LP solutions.

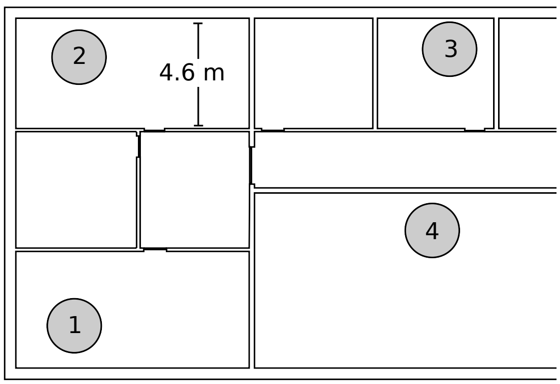


Figure 8: Position of the nodes during the experiment.

solver used by the TBF.

6.3 Hardware Validation

The suggested work was validated using real world measurements. To test this the four nodes were placed in the lab floor as shown in Figure 8. BPSK modulation was used throughout this experiment. The procedure went as follows:

1. Estimate Channel Coefficients
   (a) Node 1 transmits at maximum tx-gain of 30 dB ($G^T_{\max}$) while rx-gain equals zero.
   (b) The rest of the nodes 2, 3, and 4 measure received power for 10 seconds.
   (c) Subtract 30 from all measurements; this gives h_{12}, h_{13}, and h_{14}.
   (d) The transmitter is changed and the same steps are repeated for the rest of the nodes until all channel coefficients were measured.
2. Solve the optimization problem to obtain values of tx-gain and rx-gain.
3. Test the validity of these gains.
   (a) Node 1 sends packets using the tx-gain obtained from the optimization problem.
   (b) The rest of the nodes 2, 3, 4 listen for packets using the values of rx-gain from the solution for 20 seconds.
   (c) Nodes 2, 3, 4 report the packet delivery ratio and the power received at each node.
   (d) The transmitter is changed and the same steps are repeated for the rest of the nodes.

These procedures were continuously repeated over a twenty four hour period from 12 PM to 12 PM the following day in the lab facility. During these tests, the TBF was used. Although, in Figure 2, the threshold for received power for a link to exist $P_C^{X.BPSK}$ is around -90 dBx, $P_C^{X.BPSK}$ was set to -85 dBx to avoid a zero slack solution. Increasing $P_C^{X.BPSK}$ method will only work in a good placement (with channel coefficients of links desired to be disconnected much lower than that of the connected ones). In a problem with bad placement, this change could make a solution which is feasible at -90 dBx infeasible. The MMSF is superior in this aspect as it avoids zero slack solutions if possible without having to increase $P_C^{X.BPSK}$.

Figures 9 — 11 show a subset of the results where node 2 is the transmitter. Each point in these figures represents a single result. In Figure 9, the measured channel coefficients between node 2 and the rest of the nodes are shown. Figures 10 and 11 show the received power in dBx and the packet delivery ratio during the evaluation of the calculated gains, respectively. Figure 11 shows that nodes 1 and 3 were capable of receiving packets with delivery ratio of up to 99% while packet delivery ratio of node 4 was almost equal to zero percent the entire time except at the period from 10 PM to 11 PM. The experiment was run in a lab during a normal work day, so in the period from 9 AM to 5 PM people where present this reflected in variation of the channel coefficients. From 10 PM to 11 PM a meeting was held in the room where node 1 was placed, and this led to big variations in the channel during the experiment. This caused the undesired reception of node 4 from node 2. Similar curves were obtained when nodes 1, 3 and 4 were transmitting. From these curves, the diagonal links that we wanted to be disconnected showed low packet delivery ratio with minor disturbance at the morning period, and side links were always connected.

This proves that our method was capable of setting the gains to values that realize our desired topology. This was demonstrated with over 290 runs using the previously described procedures over a period of 24 hours.

7. LIMITATIONS

The suggested method has its limitations. The ability of this scheme to implement a topology is limited by the channel coefficients and hardware characteristics. For example, if all nodes were placed far from each other and the maximal transmitted power level and receiver

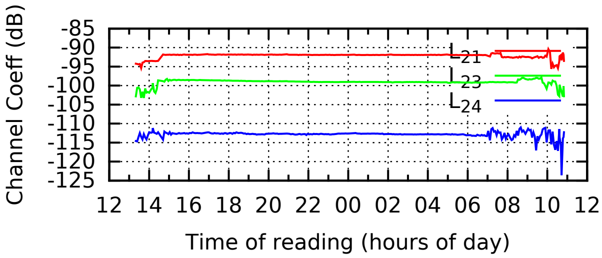


Figure 9: Measured channel coefficients.

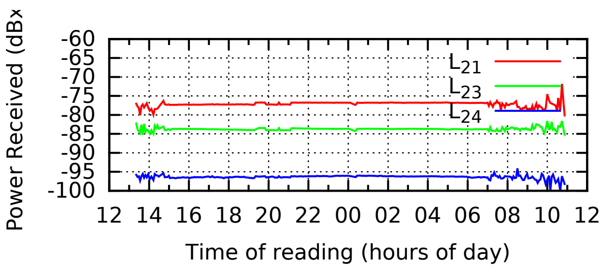


Figure 10: Power received while testing the solution.

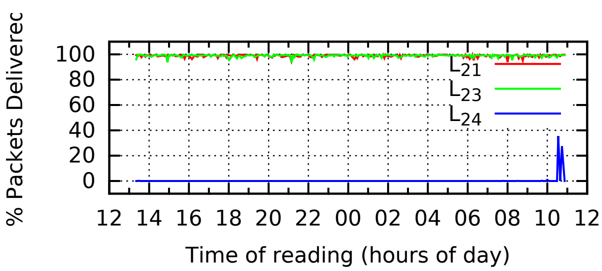


Figure 11: Packet delivery ratio while testing the solution.

gain of the hardware are not high enough, this method will fail to connect any of the nodes. Other than the obvious cases, some combinations of channel coefficients alongside with hardware constraints might fail to implement a set of topologies. These impossible to realize topologies make the optimization problem infeasible to be solved under the given constraints. Also, increased activity in the place where the experiment is conducted might affect the validity of the gains obtained.

The gain optimization problem discussed assumes that the physical nodes have been mapped adequately to the nodes of the topology. If the mapping has been performed illogically, this method could return an infeasible solution. For example, assigning nodes disconnected in the topology to physical nodes placed closely, while nodes connected in the topology to hardware separated by a long distance is very likely to be infeasible. A more logical mapping might, on the other hand, make this problem solvable.

8. CONCLUSION

In this work, we presented a method to realize a desired topology in a wireless testbed with fixed nodes by varying the transmitted power and the receiver gain. Two formulations were first developed one focuses on maximizing slack (MMSF) and the other on having a solution favoring transmit gain (TBF). The characteristics of a hardware platform were studied to obtain the values of the parameters of the problem. A case study was then developed using a square topology. An evaluation of the two methods was performed which showed that TBF is superior as it gives bigger transmitter gains, while MMSF gives a more robust solution with a bigger value of minimal slack. Real world testing was carried over an entire day and it proved the effectiveness of our proposed formulations in achieving a desired topology in a real environment.

9. ACKNOWLEDGEMENT

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